Customers Interruption Costs in Power Systems

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ABSTRACT OF THE
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Daily life activities require a continuous supply of electric power. The demand for continuous electric supply has become vital and necessary for all societies. To achieve the demand for the electric power required, there must be a well-developed power system to deliver sustainable, affordable prices, and more reliable electricity to customers. Therefore, previous studies have been studied in order to present methods used to interrupt customer interruption costs. Nonetheless, there are common challenges among all studies, such as the strategic responses with customer survey methods. Furthermore, previous research aims to use the data gathered from the customer surveys and integrate it with an indirect analytical method. The motivation behind this work is that when an outage occurs, companies suffer from significant losses, but if factors that can minimize the losses are well studied, then companies would know how to be prepared for blackouts with a minimum amount of losses. Consequently, a comparison between customer interruption costs calculations was conducted for the industry sector. The comparison conducted was based on a critical review analysis. Furthermore, after the critical review was made, all possible solutions researches has reached to were listed in order to seek opportunities for further developments. Moreover, the estimation of CICs for industrial sector in South Korea was found to be 1.3 times higher than the simple VoLL calculations. Also, all of the studied cases had suffered from the small size of data collected and the reliability of the responses. In Comparison of the cases studied, approaches to estimate CICs in paper [50] presented unique set of solutions that made it stand out. Besides estimating variables which have an effect on the CICs like [40] new SSCDF were introduced to meet each sector specific needs. The new functions CICpp, CICae, CICva, CICu, CICp and weighing factors Ku and Kp made it easier to reach reliable figures when estimating CICs.

Keywords: Customer interruption costs, monetary worth, customer survey, blackouts, indirect analytical method

Preface

23.11.2020 Abdelgani Al-Jayyousi

″And We have made the night and day two signs, and We erased the sign of the night and made the sign of the day visible that you may seek bounty from your Lord and may know the number of years and the account [of time]. And everything We have set out in detail.″(Al ESRAA 17:12). I am very grateful for the

opportunity that allowed me to pursue my dream in studying at Aalto University and getting a master′s degree in Advanced Energy Solutions Sustainable Energy Conversion Processes. First of all thanks to God for his blessings. Thanks to Professor Matti for his support. Thanks for family and friends for making this possible and for their continues support. Thanks to my fiancée for being there for me all the time. I hope this research adds to the field of energy and allows other researches to reduce the gaps in calculating customer interruption costs.

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Abbreviations

Abbreviations

DW	Direct Worth
VoLL.	value of lost load
WTA	Willing to Accept
WTP	Willing to Pay
CIC	Customer Interruption Cost
DSO	Distribution System Operator
OECD	Organisation for Economic Co-operation and Development
GDP	Gross Domestic Product
GNP	Gross National Product
TSO	Transmission System Operator
EI	Electricity Intensity
CDF	Customer Damage Function
CICp	Customer Interruption Cost Peak Power of the Customer Energy consumption
CICe	Customer Interruption Cost Annual Energy Consumption
CICva	Customer Interruption Cost of Value Added
SSCDF	Subsector Customer Damage Function
CICae	Customer Interruption Cost Annual Energy Consumption
CICpp	Customer Interruption Cost Peak Power of the Customer Energy Consumption

1 Introduction

1.1 Motivation

Daily life activities require a continuous supply of electric power. The demand for continuous electric supply has become vital and necessary for all societies. To achieve the demand for the electric power required, there must be a well-developed power system to deliver sustainable, affordable prices, and more reliable electricity to customers. However, electricity interruption will cut the daily life activities and question the reliability of the electricity suppliers. Besides reliability, electricity interruption will cause economic losses with defined values, but these interruptions' monetary worth is the research's primary objective. Before discussing customer interruption cost calculation methodologies, it is necessary to understand the nature of the power interruptions. Power interruptions are classified into momentary, sporadic, and chronic interruptions. Momentary interruption lasts for less than 1 second, while sporadic and chronic interruptions last for more extended periods that vary from minutes to hours, respectively [1].

Natural disasters are the leading cause of power outages, such as global warming, storms, and floods. Each natural disaster leads to a long and extensive blackout in the electricity. To stand against these natural disasters, investments are made to strengthen the infrastructure that will result in a more reliable system. Moreover, the assessment of determining the monetary worth of the power interruption is still an interesting topic to be studied as there has not been a proven method to calculate the customer cost interruption costs. Going through the literature, there are three methods to determine customer interruption costs that are indirect analytical methods, customer surveys, and case studies [2]. Since Finland has a moderate economy and the competitive electricity market, Finland has become an appropriate country to consider the cost of interrupting power for the industrial sector [3],[4].

1.2 Research Objective

Electricity supply continuity is essential for the continuous development of industries and rolling to life routines. Therefore, previous studies have been studied in order to present methods used to interrupt CICs. Nonetheless, there are common challenges among all studies, such as the strategic responses with customer survey methods. Therefore, previous research aims to use the data gathered from the customer surveys and integrate it with an indirect analytical method. The motivation behind this work is that when an outage occurs, companies suffer significant losses, but if factors that can minimize the losses are well studied, then companies would know how to be prepared for blackouts with a minimum amount of losses.

On the other hand, understanding the nature of responses and the company's losses from a power outage will help the DSOs estimate reasonable prices for CICs. Hence, the research aims to develop a precise hypothesis in the studied topic to enhance future research quality and allow potential solutions to be implemented by comparing and summarizing different research methods used to estimate CIC.

1.3 Thesis Structure

The introduction section of the thesis explains the motives behind this research and defines the research hypothesis. After setting the research objectives, a state of the art is conducted to summarize the previous studies goals and build upon the latest developments. After that background information explains how natural disasters can cause power interruptions and what are the economic impacts of these power interruptions. Also, this section includes how power interruptions are characterized. Furthermore, extreme weather events that happened in Finland such as Cyclone Dagmar and its effects was mentioned in this section as well. In order to have a better understand of power interruptions a case study from South Korea was examined just after Finland case study. Moreover, approaches from the literature section summarize the methods used to estimate CICs.

After a literature review is done, this research focuses on summarizing key points from the literature about the causes of power interruptions through presenting cases from the literature like Cyclone Dagmar in Finland and later show methods used to approach reliable CICs for industry sector. The critical review proposed in this paper helps in minimizing the bridges between literature information and proposing new potential solutions for CICs as listed in the research methodology section. Then, three papers were studied in the research findings section. Consequently, results of the critical review made was discussed in the discussion section. Finally, Conclusion section summarizes the whole research process and states the main point of this paper.

2 State-of-the-art

Power outages must be defined and having a knowledge about their causes is essential in order to reach for better solutions. To begin with, power interruptions are a result of unexpected outages or planned outages. The unexpected outages are caused by extreme weather events such as storms, hurricanes, and massive snowstorms. Moreover, there are other causes for minor power outages such as fallen trees, broken components, animals and lightening. On the other hand, planned outages are results of the maintenance or development of the electrical network. Moreover, those power interruptions are split into different categories according to their duration, such as momentary, sporadic, and chronic interruptions [3]. There are currently three methods to assess CICs: customer surveys, indirect analytical methods, and case studies. According to the literature, The most widely used method is the customer survey method [3].

There are three common approaches in the customer direct worth (DW) approach, willing to pay (WTP) approach, and willing to accept (WTA) approach. In the DW approach, respondents are requested to estimate their losses given different outages scenarios. Usually, the questionnaire is done through one-to-one interviews, phone calls, or emails. Furthermore, customers are asked how much they would pay to avoid power outage in the WTP. However, customers are asked how much compensation should be paid to accept the outage in the WTA.

The advantage of implementing the customer survey method is that it can be tailored and collects specific information, which helps estimate power outage characteristics to reach out to a definite conclusion in CICs. Likewise, some challenges arise with the customer survey approach. For example, some customers tend to exaggerate their losses giving unrealistic values, so it becomes a challenge to deal with subjective responses and eliminating zero responses. Also, it is expensive to run studies on customer surveys can be found in [3],[4],[5],[6].

Besides customer surveys, an indirect analytical method is a preferred approach as objective data like electricity prices, annual energy consumption, gross domestic product, and value added data are accessible and in reach. The studies [8],[8],[9],[10] are examples of an indirect analytical method. Moreover, the indirect analytical method's advantages are that it is a straightforward method, fast and cheap compared to other methods.

Furthermore, in the case of significant blackouts, case studies are preferred as a method to estimate CICs. Case studies are considered the most accurate as customer surveys, and indirect analytical methods are implemented within the case studies. However, occurring of major blackouts is rare to happen compared to occurring of shorter power outages. Because of the frequency rate of major blackouts to happen and the high costs associated, approaching CICs through case studies is considered challenging. Hence, case studies in the literature are not as much as other methods. Examples of case studies from the literature can be found in New York City Blackout of 1977 [11] and Storm Gudrun of 205 in Sweden [12]. Nevertheless, the study [13] assesses in detail the advantages and disadvantages of each CICs method. Studies [14],[15] target CICs for the European Union and Italian residential sectors, respectively.

3 Background or Literature Review

3.1 Effects of natural disasters

First of all, it must be noted that power outages lead to the end user loss of power. High winds can damage electricity, especially when combined with seasonal storms, leading to interruptions of service for large numbers of electricity users. Whereas most power outages are due to damage caused by trees and tree limbs that fall on local power supplies and poles, the major power outages tend to be caused by damage to transmission lines that carry large power over long distances. The electricity outages can last several hours or extend to several days depending on the intensity of the storm or the resulting problem. This, can have real economic consequences as power outages can affect companies and producers (mostly due to loss of goods and inventory damage and orders).

3.1.1 Economic impacts of natural disaster on power systems

In a perfect scenario, the electricity supply must meet the demand. When a natural disaster occurs, it affects the supply-demand cycle. This is because electricity has to be suspended in one place to prevent complete network failure. Hence, a shortage in electricity supply is created, and demand has increased. The result will be a rise in the prices due to the blackout that happened because of the natural disaster.

With many such incidents occurring in Europe, some events were taken into considerations. For example, in 2003, large scale interruptions in London, Copenhagen, and Italy resulted from network failures. Nevertheless, in 2003, the summer was hot and dry, which caused power stations to run out of cooling water, leading to a pause in electricity production. In the Netherlands, for example, power generation was reduced in such a way that prices increased dramatically on the spot market. Large energy users responded to price increases by decreasing the output to sell the electricity they bought at low prices earlier. In addition, TenneT – a Netherlands transmission systems operator (TSO) – ordered the Netherlands public to limit the use of electricity, in order to avoid rolling power interruptions.

3.1.2 Characterizing interruptions of supply

The effects of one interruption of supply varies from one to another for several reasons.

- Users of electricity consist of different groups. therefore, consequences of power interruptions in private households are different than power interruptions in health sector like hospitals or industrial sector.

- The level of reliability perceived: the more reliability perceived, the less industrial, service and private sectors are vulnerable to measures of caution and the more harm caused by power interruptions.

- The type of activity which gets suspended by power interruption is determined by the moment the interruption happens, season, during which week days and during the time of the day the interruption occurred. For instance, if a power interruption occurs at 8 p.m. then leisure activities like watching television gets affected for electricity in the private sector. whereas, if the power interruption occurs at 3 a.m. there will be less affected people since most people would be sleeping at that time for the private sector.

- Economic costs are determined by the duration of the power interruption. Power interruptions damages can vary from loss of production for the industrial sector to loss of leisure time for the private sector. Moreover, each damage length depends on the duration of the power outage. However, some damages would start a while after the interruptions occurs like spoiling of food in fridges.

- If the interruption is announced before it occurs, then damages affecting the economic costs can be minimized. for instance, if users of electricity for the industrial sector were told that there will be an interruption, backup generators would start working to prevent loss of production during the period of power interruption.

- When the interruptions are systemic for example, day by day rather than being accidental, the effects of power interruptions are smaller. When the interruption is systematic people tend to prepare for it even though it has not been announced earlier.

3.2 Extreme weather events in Finland

The extreme weather conditions in Finland adapted the electric power system to withstand extreme conditions. Although Finland has a forceful infrastructure that enabled it to have a high level of reliability until the years before 2010, in late July 2010, Finland was hit by severe storm along with thunders [16]. Thus, the Finnish authorities started to make improvements in the electric power system to make it resilient towards extreme weather events. The thunderstorms reached a high record of 170.000 registered ground flashes, which is considered 20% higher than the long term average. These storms led to excessive damage, such as falling trees on the aerial distribution lines. Moreover, extensive blackouts occurred through

Finland as a result of the thunderstorms. Hence, out of 3.2 million electricity customers, around 481,000 experienced electric power interruptions [17].

3.2.1 Cyclone Dagmar

In 2011 in the last week of December, Finland was hit by one of the strongest storms known as Cyclone Dagmar. Cyclone Dagmar is known as Tapani, which hit Finland on the 26^{th} of December, and Hannu storms that hit Finland on the 27^{th} of December. Furthermore, the Scandinavian Peninsula was hit by cyclone Dagmar and towards the Finnish gulf and to the Baltic Sea.

3.2.2 Effects of the storm in Finland

Although Finland had a robust electric power system, being hit by such a storm made the authorities question the current electric power system and make the electric power system more reliable. Because of the storm that hit Finland in 2011, power interruption was noticed across the country, and the interruption duration was changing from minutes to days to weeks in some places [17].

The storm's significant impact was seen as cities turned into darkness, electric heating was missing in a vast number of households, hot water service, and wastewater problems roused. Moreover, in some places, residents were asked to limit their water usage due to the water shortage because of the storm and the long hours of electric power interruption. Also, daily life was somehow set on a pause because of the electric power interruption as the food was getting spoiled, automatic doors in hospitals stopped working, and the social activities were canceled.

As a result of the storm, about 570,000 customers experienced power interruption out of 3.2 million electricity customers. Other impacts of the storm were seen as the falling of trees to the roads, which interrupted transportation in Finland. The fire brigade in the south east region made about 2500 rescue missions, which is considered to be about 20% of the total rescue missions in a year [18]

Unfortunately, two people were reported to lose their life as a result of the storm [17]. Fig.1 shows the duration of the power outage duration experienced because of the storms 2010 and 2011. As a result of the storm or Tapani storm, the Finnish authorities and the society observed how much their daily routines and social life depend heavily on the communication service. Because of the power outage, communication service was suspended in different parts of Finland. In 2013 Finland went through hard times again as it was hit by another storm called Eino, which hit Finland in October 2013. The storm caused interruptions in the electric power system resulting in a power outage for 250,000 customers [19].

Besides, the storm caused trees to fall on the transmission lines and caused it to trip as declared by the Finnish transmission system operators (DSO) that could be fixed within 40 minutes [20].

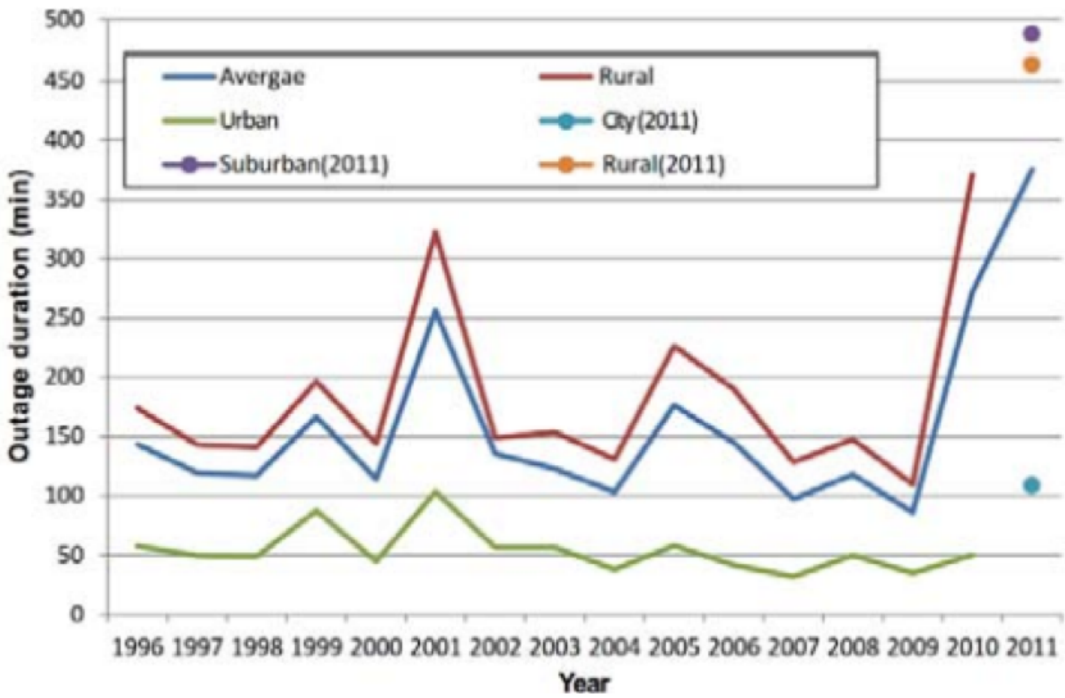

Figure 1: Average outage duration for distribution system for each secondary substation [18].

Moreover, the Eino storm has caused noticeable damages to the distribution level. The DSO Elenia was heavily affected by the storm, as 92,000 customers experienced power outages [22]. Another storm called Valio hit Finland in Autumn 2015, which led to power outages in more than 170,000 households [22]. Moreover, snowstorms caused long-lasting blackouts near central Finland, and the storms continued during the whole winter [23].

Fig.1 shows the power interruption duration between the years 1996 and 2011. The Finnish electricity distribution system was grouped into urban and rural area distribution before 2011. As a result of the storms that hit Finland from 2010 and ongoing, the authorities decided that the differences between the areas of distribution must be altogether distinguished, and therefore, new regulations and rules must be implemented.

In order to achieve the goal, regrouping of the distribution system in categories was made. The categories were set as urban, which is city area, suburban and rural areas. Furthermore, the amount of energy supplied, the number of electric power subscriptions, and the power network's length was assigned to know the power outage criteria. The effects of the storms can be seen in Fig.1. During the years 2010 and 2011, the average outage duration is increasing in the suburban and rural distribution areas. Likewise, in urban areas, the outage duration is much lower between 1996 and 2011.

These differences between the urban, suburban, and rural areas in outage duration are related to the structure of the Finnish electric power network. The majority of the medium voltage, over 70%, runs through the forests where the medium voltage network is 130000 km long, and about 88% contains overhead lines. Since most network lines pass through forests, it makes the process of repairing and fixing the power interruption harder and requires more time. The outage can be caused as trees fall over the transmission lines leading to power interruption.

Nevertheless, the degree of cabling in low voltage network increases in the urban area. The degree of cabling is below 30% in a rural region, whereas it is 38% in urban areas in all low voltage network [24]. The degree of cabling must be increased in rural areas as 58% of Finland's electricity customers live in rural areas. Thus, it is essential to increase the level of reliability. In 2003 Finland introduced a maximum allowable time limit for a single interruption and set different penalties that change with the interruption duration. Energy Market Act of Finland stated that if the time limit of the interruption exceeds the maximum limit, then the DSO is forced to compensate the customer [18].

3.2.3 SAIDI TOOL

System Average Interruption Duration is a standard tool used to interpret the reliability as follows [2],

$$SAIDI = \frac{total\ duration\ of\ sustained\ interruption\ in\ a\ year}{total\ number\ of\ customers}\ (h). \tag{1}$$

SAIDI tool has been used to interrupt the reliability of electricity in Finland between 2007 and 2014. Fig.2 shows the yearly change in SAIDI hours and listing the reason that caused the power outage to occur [26].

Continuing after the year 2011, natural events such as storm, hurricanes, thunderstorms, and snowfalls were still causing major blackouts years after. Furthermore, Fig.2 classifies the outage reasons as planned, technical nature, and others, such as repairing or maintaining the transmission lines. As seen from Fig.1, natural disasters are causing the primary power outage in Finland as it hit the maximum of power outage duration in 2011, and in 2010 and 2013, the outage hours were

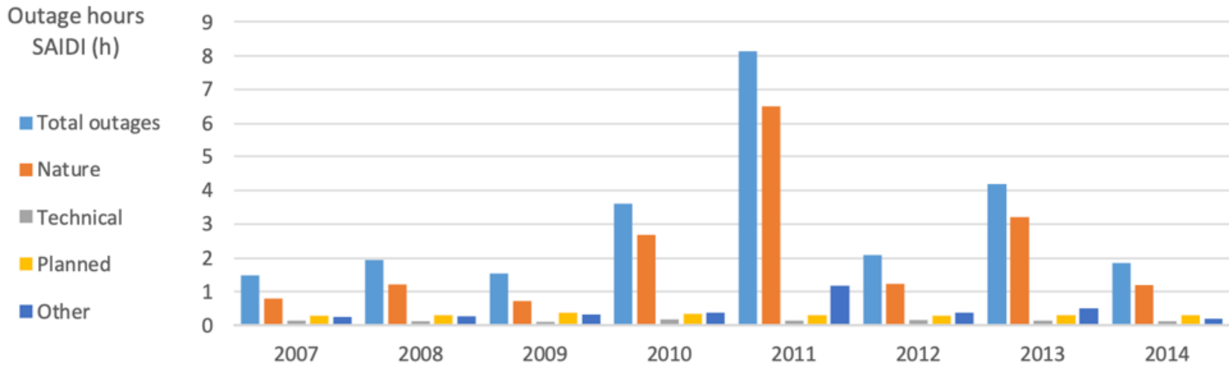

Figure 2: SAIDI outage hours for Finland during the years 2007-2014 [26].

much higher than other years due to natural effects. Thus, natural disasters are considered to be the main challenge facing the Finnish electric power system.

On the other hand, SAIDI outage hours did not reach two hours in other years, excluding the years 2010, 2011, and 2013. This supports the fact that Finland's electric power system threats are natural disasters. In Fig.3, natural disasters are broken down in more depth to see which natural disaster affects the outage hours the most [25].

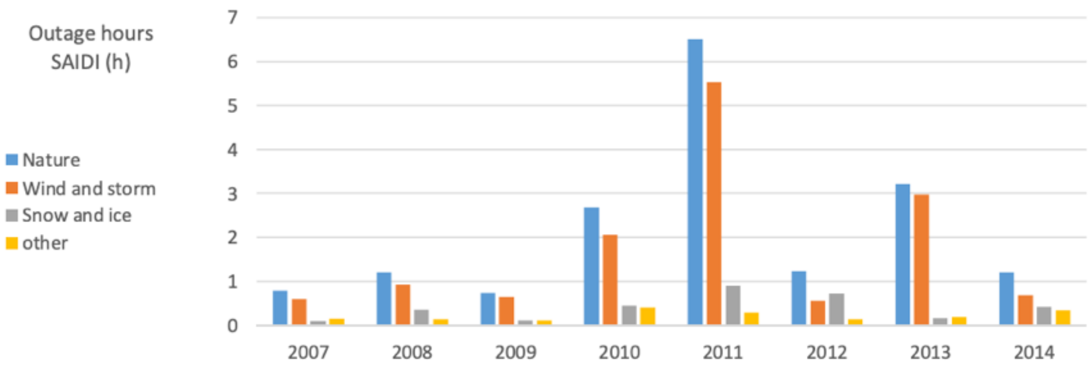

Figure 3: Natural SAIDI outage hours for Finland during the years 2007-2014 [26].

Fig.3 shows that wind and storm is the main reason behind the power interruption, causing extended-lasting outages. In contrast, the power infrastructure can withstand long winters. Nevertheless, the number of extreme weather events and the frequency of occurring are noticeably increasing in the last decade [27]. Additionally, in case of long lasting outages, Finland is considered to be in the lead in offering standard customers compensations.

In 2003 the Energy Market Act of Finland started legislation that put the maximum allowable single power outage duration under a known definition [28]. However, various unallowable outage duration were subjected to definite penalties. After the legislation has been set, if an outage exceeds the maximum allowable duration for a single event, the DSO is obliged to compensate the customer with the corresponding percentage of the annual electric power fee. Moreover, there has been an update in the standard customer compensation in 2013, after the natural disasters in 2010 and 2011 [29]. Compensations made in 2003 and 2013 are shown in tables 1, and 2, respectively.

Table 1: Compensation scheme for customers in accordance with the legislation adopted in 2003 in Finland [29].

Outage time (h)	**Compensation (%)**
12 - 24	10
24 - 72	25
72 - 120	50
>120	100

Table 2: Standard compensation for customers in accordance with the legislation adopted in 2013 in Finland [29].

Standard Customer Compensation (2013)	
Outage time (h)	*Compensation (%)*
12 - 24	10
24 - 72	25
72 - 120	50
120 - 192	100
192 - 288	150
>288	200

From Fig.1, if the interruption time exceeds 120h, then the DSO is forced to pay 100% compensation to the customer. The compensation percentage refers to the amount of annual electricity fee the customer paid last year before the year of the interruption to the DSO. Furthermore, it has been decided that the maximum amount of money a customer can receive in a year is 700 Euros. Fig.4 shows the standard amount of compensation paid from 2005 to 2011 [28]. Because of the storms in 2010 and 2011, there was a noticeable increase in the penalties.

The compensation scheme of 2003 had to be studied again as the time caps were not suitable to meet the extreme events that happened in the years 2010 and 2011 in preventing long blackouts. Therefore, in 2013 the Finnish government had to update the Energy Market Act policies related to outage penalties and set new time caps and new penalties for the power interruptions outages. Moreover, the maximum amount of money a customer can receive in a year has been raised to 1200 Euros [30].

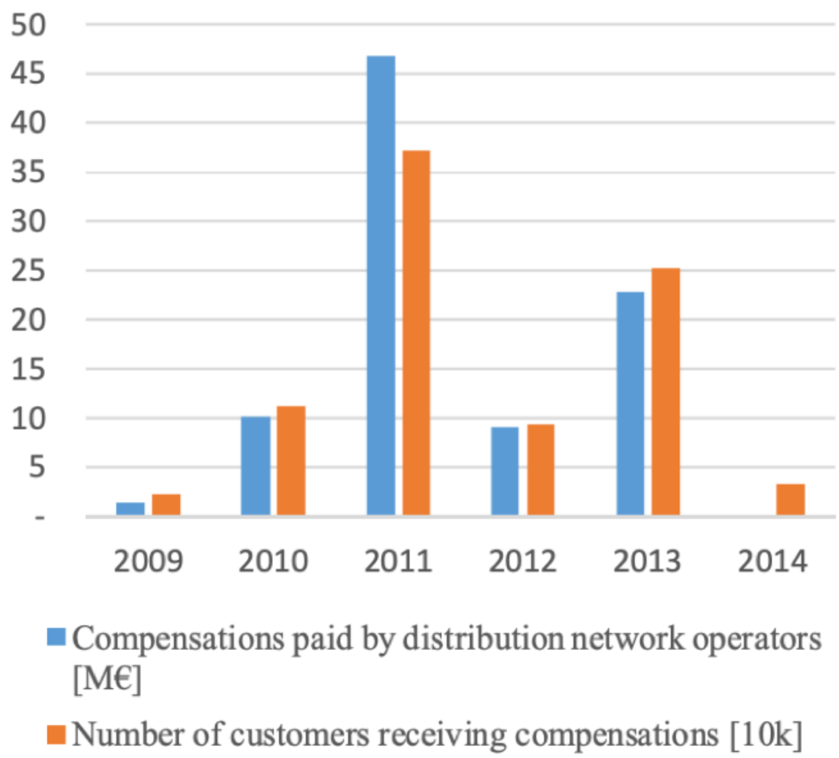

Figure 4: Number of compensations and customers receiving compensations in Finland. [26].

The acceptable single-time interruption event is 6 hours for urban areas, where it is set to 36 hours for rural areas, according to [29]. The new time caps must be complied with by utilities by then of 2028 [29]. Fig.4 shows the number of compensations paid by DSO and the number of customers receiving compensations. From Fig.4, the years 2011 and 2013, the DSO due to the natural disaster that happened paid the highest amount of compensations. In 2011, 47 million euros were paid to the customer as outage compensations, while in 2013, more than 20 million euros were paid.

In addition, Figs. 5, and 6 show the distribution of standard compensations per outage duration in 1k and M, respectively [31]. Interruptions lasting for 72 hours are the main challenge for utilities, as observed in Figs. 5, and 6. Power interruption that lasted longer can be treated as exceptional events except the year 2011. A solution degree of cabling must be increased in the distribution network for utilities to avoid power interruptions. Some plans aim to invest about 1.2 billion euros in constructing 3000 km of new transmission lines and 30 new substations within the years 2015 and 2025 [32].

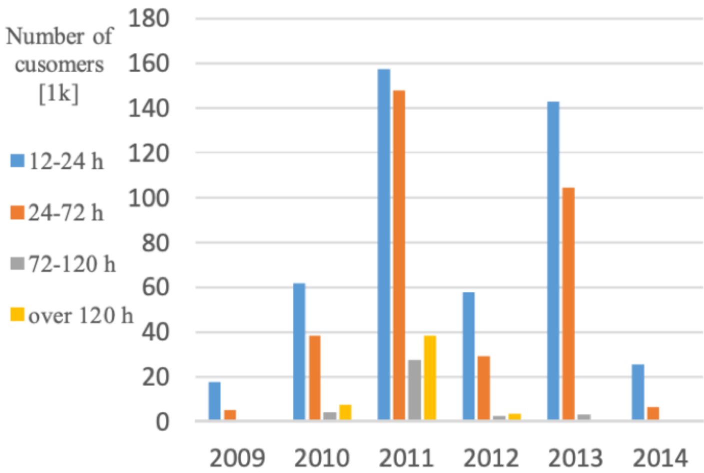

Figure 5: Standard compensation distribution per outage duration [26].

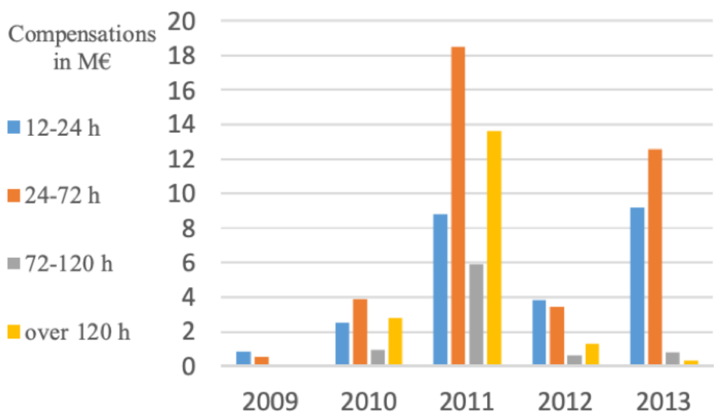

Figure 6: Number of customers received standard compensation distribution [26].

3.3 South Korea Case study

The total energy consumption of OECD had reached 9,626.78 TWh in 2013 [33], where 30.8% of the total electricity consumption accounts for the manufacturing sector, and 63% of the total consumption accounts for agriculture, public service, commercial, fishing, and manufacturing sectors. Industrial, commercial, and public service sectors are the major sectors for electricity consumption for frequent years. Power outages are occurring worldwide more frequently. This fact threatens the industrial sector and other sectors as power interruptions will lead to major economic losses [34].

The previously conducted studies focused on calculating the outage costs based on raw materials, production loss, and finished production damage. Those parameters do not include other damage costs like consumer's inconvenience because of the power outage. Outage cost for the industrial sector is calculated in terms of the value of lost load (VoLL) is implies the ratio between the GNP or GDP and the electricity consumption [35],[36].

This study analyzes the outage costs, including the direct and indirect costs for individual customers at the sector level. In this study, two cases are considered—the first case 2 hours of power interruption without announcing that the power interruption will occur. The second case is 2 hours of power interruption with announcing that there will be a power interruption. After the sudden blackout that hit South Korea in 2011, it is observed that if the power outage has been announced earlier, economic losses could be minimized in each sector.

3.3.1 South Korea electricity industry current state

The economic crisis that happened in 2009 resulted in a low economic growth rate, according to IEA (2015) reports. Moreover, there was a decrease in electricity consumption because of the energy efficiency improvements made in the manufacturing industries. In 2013 the OECD industrial electricity consumption increased by 0.6% in comparison with 2012. Electricity consumption of the industrial sector for most countries in the OECD is increasing at a constant level. Furthermore, there have been graduals increase shown by Germany and Japan from 1980 to 2012, whereas there has been a minimal decrease in 2013. However, South Korea's electricity consumption increased from 76.7 TWh to 423.3 TWh between 1990 and 2013. Sectors of South Korea are noticed to have constant electricity consumption, as shown in Fig.7.

As seen in Fig.7, a considerable amount of electricity is consumed by the manufacturing sector with a constant electricity consumption increase. The rapid increase in electricity consumption can result from the electrification of the indus-

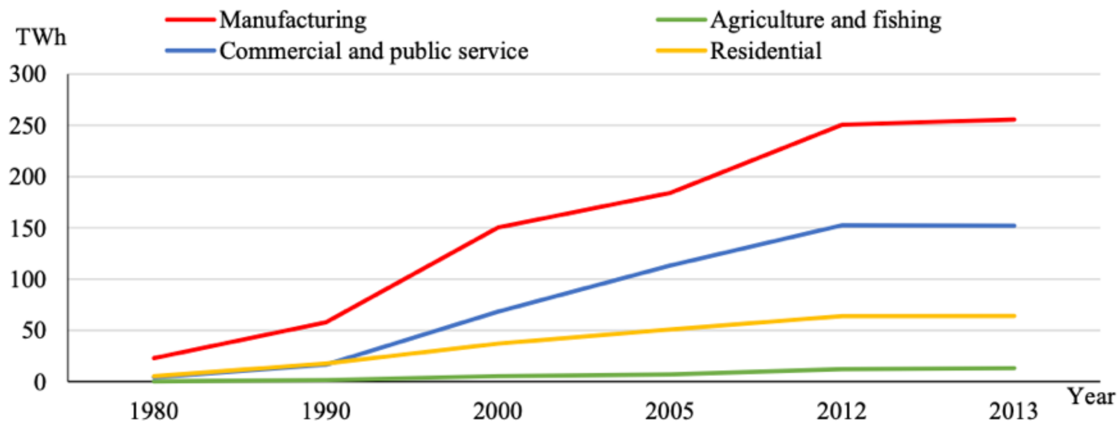

Figure 7: Sectors electricity consumption in South Korea [33].

trial sector and the increase in industrial production. Lower prices of electricity compared to other energy sources have led to fast electrification of the industrial sector, which is a result of a distorted energy price system [37],[38]. Fig.8 shows the index of the electricity price has remained almost the same with minor fluctuation since 1995 and has lower price indices than other energy sources since 2008.

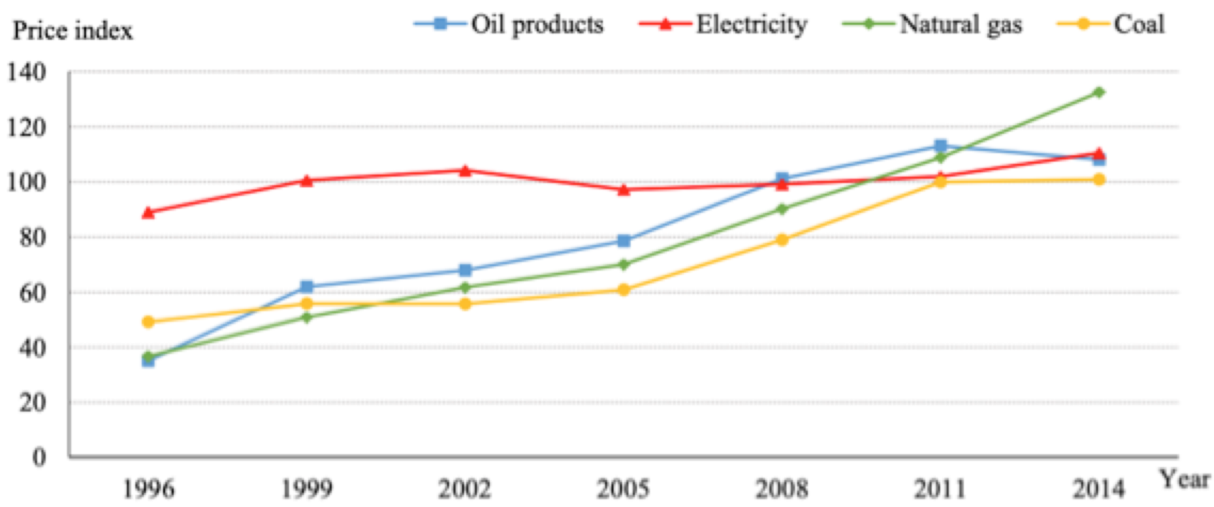

Figure 8: Sectors electricity Intensity (EI) in South Korea. [33].

Moreover, from Fig.9, it is seen that the manufacturing sector in South Korea has constant electricity intensity since 2010, while it has been higher before 2010 than in other sectors. Additionally, since there was no motivation for companies to improve their energy efficiency because of the low electricity prices, the South Korean industries' electricity intensity has not improved.

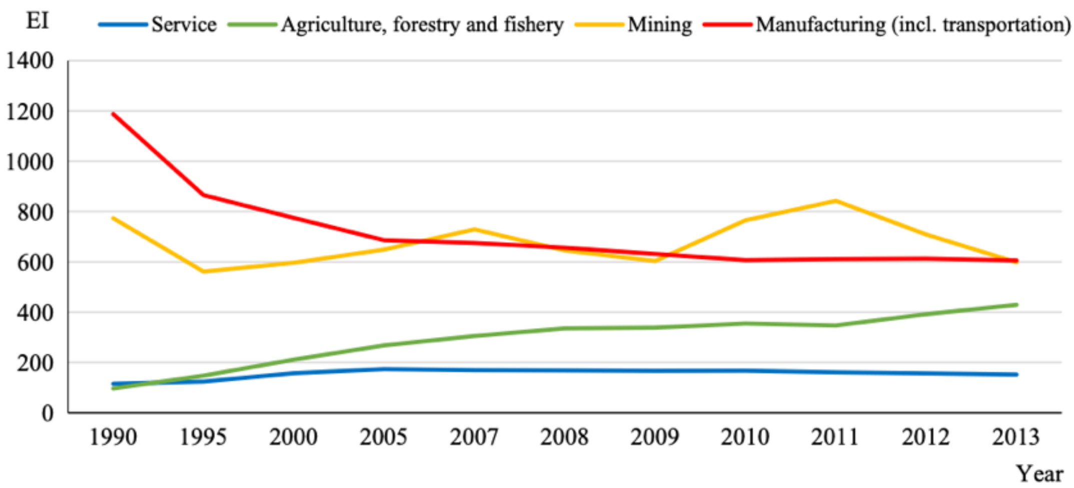

Figure 9: Price trends for energy retail in South Korea [33].

The 2011 supply reserve margin after the rolling blackout on 15 September 2011 increased to 11.5% in 2014, which the government plans to use to relieve South Korea's existing electricity shortage [39]. The Government of Korea aims to expand its capacity by constructing new coal and nuclear power plants to meet the high electricity demand. Still, due to local conflicts regarding the construction of the new power plants and transmission grid and technical problems relating to the transmission grid, concerns remain.

The industrial sector is currently the largest electricity user and will continue to expand as the economy increases. In 2013 the industrial sector consumed 86.9% of the total electricity while the residential used only 13.1%. Therefore, given the high consumption of electricity and the high EI and proportion of the electricity as a whole, it could be inferred that the industrial sector might incur high damage costs in the event of a blackout. Nevertheless, companies' flexibility and mitigation measures, such as running emergency generators, could vary those cost damages.

Study	Sector	Country	Methodology	Variables	Reported outage cost
Jackson and Salvage (1974)	Industrial (Manufacturing)	Scotland	Microeconomic model	Fixed cost (frequency), variable cost (duration)	£ 2.83/120 min (potato crisps sector) £ 5.56/120 min (paper machine rolls sector)
Bental and Ravid (1982)	Industrial	Israel/USA	Microeconomic model	Unsupplied power (yearly cost per kw of backup generator, variable cost per kWh)	$1.16 per unsupplied kWh
Subramaniam et al. (1985)	Industrial	Canada	Customer damage function	The presence or absence of a standby system, annual energy consumption, peak demand, season, and duration of interruption	$3,355 per hour in winter months (Dec, Jan, Feb, Mar; no standby system) $5.81/kw per hour (no standby system)
Billinton et al. (1986)	Commercial	Canada	Customer damage function	The presence or absence of a standby system, annual energy consumption, peak demand, season, and duration of interruption	$668.96 per hour in winter months (Dec, Jan, Feb, Mar; no standby system) $15.65/kw per hour (no standby system)
Caves et al. (1992)	Industrial	USA	Discrete choice model	Frequency, outage duration, participation in I/C program	$4/kWh for an hour interruption
Lehtonen and Lemström (1995)	Industrial/commercial/agriculture	Nordic (Denmark, Finland, Iceland)	Direct cost approach	Agriculture: peak power demand of customers, summer	Den: $66.8 per hour/kW Fin: $15.5 per hour/kW Ice: $5.6 per hour/kW
				Industry: warning system, outage duration, spoilt raw materials and damage, restart, lost production, cost to 3rd party	Den: $22.1 per hour/kW (unexpected), $5.1 per hour/kW (planned) Fin: $14.5 per hour/kW (unexpected), $6.0 per hour/kW (planned) Ice: $12.5 per hour/kW (unexpected), $3.4 per hour/kW (planned)
				Commercial: winter day during normal business hours	Den: $8.50 per hour/kW (unexpected), $4.10 per hour/kW (planned) Fin: $16.4 per hour/kW (unexpected), $10.5 per hour/kW (planned) Ice: $21.0 per hour/kW (unexpected), $14.2 per hour/kW (planned)
				Public: winter and during office hours (same as commercial)	Den: $9.0 per hour/kW (unexpected), $3.4 per hour/kW (planned) Fin: $5.2 per hour/kW (unexpected), $2.2 per hour/kW (planned) Ice: $12.0 per hour/kW (unexpected), $6.4 per hour/kW (planned)
Willis and Garrod (1997)	Industrial	UK	Contingent ranking	Day, time, duration of outage	£ 1500 per hour/ £ 3500 per outage
de Nooij et al. (2007)	Firms, government, households	Netherlands	VoLL	Types of users, electricity demand, value-added, time of day	€8.56/kW h (firms, government and household) €5.97/kW h (firms and government)
Leahy and Tol (2011)	Industrial, commercial, household	Northern Ireland/ Republic of Ireland	VoLL	Annual electricity consumption, GVA, operating (working) hours, number of workers and wage, time of day and week, type of user	NI(2007): €4/kW h (Industrial), €13/ kW h (Commercial) RI(2008): €4/kW h (Industrial), €14/ kW h (Commercial)
Coll-Mayor et al. (2012)	Industrial (Regions)	Spain	Value=EHnP×VoLL×ELP	Time/supply, GDP/TEC, loss of power	62,993.8 (k€) in 2006
Linares and Rey (2013)	Agriculture, manufacturing, construction, transport, services, government, households	Spain	VoLL	Gross value added, electricity consumption	€5.98/kW h (Total) €4.40/kW h (Agriculture) €1.38/kW h (Manufacturing) €33.37/kW h (Construction) €8.47/kW h (Services) €8.11/kW h (Households) €6.23/kW h (Government) €8.53/kW h (Transport)
Reichl et al. (2013)	Non-household (businesses, public sector entities, NGOs), household	Austria	Value-added production approach & CVM	Synthetic load profiles, data on value-added, outage characteristics (date, time, and duration)/WTP	€5.7/kW h (Non-household) €1.2/kW h (Household)

Figure 10: Industrial sector power outages studies on outage costs [40].

Study	Sector	Country	Methodology	Variables	Reported outage cost
Küfeoğlu and Lehtonen (2013)	Industrial	Finland	Direct cost approach	Duration and characteristics (unexpected or planned) of interruption	(construction sector only) €1.62 cents/kW h (unexpected) €0.95 cents/kW h (planned)
Yoshida and Matsuhashi (2013)	Industrial	Japan	Microeconomic model & Input-output analysis	Electricity consumption, labor cost, equipment damage cost, credibility loss cost, avoidable cost	672 yen/kW h (planned hour-long outage on summer weekday)
Growitsch et al. (2014)	Agriculture and fishing, manufacturing, construction, services, households	Germany (states)	VoLL	(annual) gross value added, (annual) electricity consumption	€7.41/kW h (Total) €2.49/kW h (Agriculture and fishing) €2.19/kW h (Manufacturing) €102.93/kW h (Construction) €11.04/kW;h (Services) €11.92/kW h (Households)

Figure 11: Continued.

4 Approaches from the literature

Since customer cost interruptions are high-interest topics and have got much attention, there are many proposed methods for customer interruption cost assessments. in order to estimate CICs there are three common methods that have been widely used among electrical power societies. These methods are indirect analytical methods, customer surveys, and case studies.

4.1 Indirect analytical methods

Indirect analytical methods work by using available and accessible data to study customer interruption costs. These data include the gross domestic product (GDP), the annual energy consumption, the peak power reached, the turnover, or the created Value Added of a country, region, or customer group. This method is known to be easy and straightforward. Plus, it is cheap and requires less time to follow, and it results in high objective estimations compared to other methods. Monetary losses experienced by a particular country for some time can be known by defining a customer damage function by dividing the GDP by the annual energy consumption of a specific country.

However, the results of this method are an average because each customer segment is analyzed together with distinct energy consumption characteristics. However, more customer specific findings and a low error margin are required with current market dynamics. Due to this reason, indirect analytical methods are not commonly used to estimate CICs.

4.2 Customer surveys

Customer surveys are considered to be the most preferred usable technique in calculating customer cost interruption costs. In this method, a questionnaire is given to the electricity customer, where the questionnaire includes questions about different power outages scenarios. These are the most popular tools, according to the literature, chosen and used for estimating the cost of outages by the electricity company and the utility industry.

By designing hypothetical outage scenarios with a carefully prepared questionnaire, the customer will estimate the economic losses incurred during that predefined scenario. The customer survey method depends on a questionnaire given to people because the respondents well be the most suitable to determine their losses. Being customers specific is a key role in the customer survey method, thus it is preferred among other methods. The questionnaire is designed to meet specific scenarios and collects respondents answers to measure encountered economic losses for each scenario.

Customer survey data can be collected through three methods. First method is defined as Willingness to Accept (WTA) method. In this method an amount of compensation is defined by the respondent for the willing of accepting an experience of a hypothetical power interruption. The second method is defined as Willingness to Pay (WTP) method. In this method the respondent defines an amount of money in order to avoid a power interruption.

The WTA and WTP results should be identical to the objective evaluation in theory. moreover, worth of a specific spoiled material should be independent of evaluated the cost and should be the same. Because in a specific environment the economic worth of a single power interruption should be unique.

However, the unpleasing fact about WTA and WTP is that some respondents tend to exaggerate their economic losses, some might be in a rush resulting and misleading results and some might pay to less in order to avoid a power interruption or asking for a high compensation to avoid the power interruption. These kind of responses question the credibility of the data collected and making a huge gap between WTP and WTA methods. Therefore, it is must to set some boundaries to make these methods valuable for research.

Direct Worth (DW) approach is the their method for collecting data for a customer survey. in this method the respondent is asked directly to evaluate the experienced losses, through a prepared questionnaire for different power outage scenarios. Furthermore, in this method the human bias is reduced because economic losses are being directly assessed. Although this method is considered to be the most reliable among other method, it has drawbacks. The challenge arise when handling with strategic responses and zero responses. These challenges question the credibility of the (DW) approach as well. likewise, there certain methods used in the literature in order to eliminate these responses as presented in this paper in section 6.

4.3 Case studies

Case study approach is the last method and considered to be least preferred method among other methods by researches. When extreme weather events occurs massive blackouts are resulted affecting huge populations and leading to major economic losses. Nevertheless, case studies are considered to be the most accurate methods among other methods in estimating CICs. The data are accurate because case studies are carried just after an event occurs. As result, the respondent is in a suitable situation to estimates the economic of value of the losses after experiencing a power interruption. Likewise, because such cases are rare to happen, it is expensive to conduct case studies method making it less preferred and attractive to professionals.

5 Research methodology

A comparison between customer interruption costs calculations made in the industry sector will be conducted. The comparison will be made based on a critical review (integrative review) of [40][50][51].

According to the article [41] detailed description of how to choose a method to review the literature can be found in [41] the integrative review or critical review choice criteria are summarized in Table 3.

Table 3: Criterion for selecting integrative review [41].

Approach	Integrative
Typical purpose	Critique and synthesize
Research questions	Narrow or broad
Search strategy	Usually not systematic
Sample and characteristics	Research articles, books, and other published texts
Analysis and evaluation	Qualitative
Examples of contribution	Taxonomy or classification

The integrative review aims to evaluate, criticize, and synthesize a research topic's findings to allow new theoretical frameworks or models to emerge [42],[43]. Therefore in this thesis, the integrative review method is used to overview the knowledge base, provide a critical review and measure how the customer survey method is implemented in the industry sector to calculate the customer interruption costs. Hopefully, after the integrative review is done, it will allow for more research to continue in the studied model for calculating the customer interruption cost. Also, research gaps in the effectiveness of the survey methods implemented in the industry sector will be identified faster than conducting new research and discovering what areas need development.

5.1 Integrative review steps

The listed articles will be reviewed according to the steps mentioned in Table 4 below.

Table 4: Review points of suggested articles.

Review point	Description
Review point 1	Introduction and literature review from the author
Review point 2	Model used
Review point 3	Results and discussion
Review point 4	Conclusion

Each paper will be reviewed according to the steps listed in Table 4. The first step includes stating the literature review the author used in his article. This step aims to find out what has been done before the author had contributed his work and to study what has been done before. This step is essential because it is the foundation that leads to new potential solutions.

The second review point is to list the methods used to find the results. This important to understand how the results were conducted, and in case of errors, future research can be done specifically on the models implemented in the listed articles to improve it and achieve better results.

Furthermore, the third review point is results and discussion. This point is crucial as it mentions the results the author reached after the studies conducted and show how effective the method is in finding a solution to the stated problem.

Finally, the final review point is the conclusion. This point summarizes all work done and put together all the necessary information obtained from the article, making it easier and faster for the reader to sum up the process used and have an idea about the achieved results.

Consequently, after each article is reviewed, a comparison of those four review points will be made between the three articles stating all possible differences and similarities.

6 Research Findings

6.1 Estimation of power outage costs in the industrial sector of South Korea

6.1.1 The model

The author used survey data in order to estimate the power outage cost. Since there are no costs in negative values and the dependent variable is outage cost, the author used the Tobit model to estimate the power outage cost. According to [44],[45], when the range of values is limited Tobit model is suggested as a model. The full model can be reviewed in the article [40].

6.1.2 Data and survey design

The survey included two scenarios, scenario 1 is the unannounced outage and scenario 2 is the announced outage. The survey aims to estimate the inconvenience of the customers and economic losses for the industrial sector using the suggested scenarios. The survey questionnaire includes two sections. In the first section, respondents asked questions regarding the company's background information, such as its location, industry type, the company's electricity consumption, contract electricity amount, electricity peak time consumption, employees working full time, and the annual sales.

Moreover, the second section includes damage costs caused by the power outage. In this paper, total outage costs are being estimated by considering the various damage types suggested by previous studies. Hence, the author put together eight different kinds of damages that the companies have to pay for in case of an outage.

Table.5 shows the different types of damages with a description of each damage. Furthermore, more than one damage can occur at once. Therefore, a single company can select multiple damages that occur together when a power outage happens. As seen from Table.5, production loss has the highest ratio, among other damages. Questionnaire details such as the time, season, and duration of the outage when the outage occurs, company's demographics, emergency generator capacity, and company's outage cost can be reviewed in the article [40] which the author has taken from [37].

Table 5: Description of the different types of damages considered in the survey questionnaire. [40].

Damage	Description	Ratio (%)
Production loss	Economic loss of the final product, which is not produced during the power outage period until the restart of production.	22.1
Overtime to make up lost production	All the costs, including those for additional time, service, and operation incurred by overtime work to make up for lost production; It includes additional costs due to outages, such as overtime pay for night work, which a company is not entitled to pay.	17.2
Raw materials and finished product damage	The cost caused by damage of raw materials and final product due to the power outage.	18.3
Plant/equipment damage	The cost of damage related to plant or equipment that are burnt or damaged due to the power outage.	10.3
Start-up cost (extra cleanup and maintenance)	The cost of extra cleanup and maintenance for normal operation of the product line after the power outage.	15.5
Emergency generator operation	The operation cost of the emergency generator (emergency power supply system) when it is operated during the power outage such as fuel cost.	4.1
Environmental damage	The cost of damage caused by the leakage of contaminants due to the power outage.	4.2
Others	Other costs which are not mentioned above.	8.3

6.1.3 Results and discussion

Table 6: Results of Type II Tobit model estimations for the industrial sectors [40].

Variables	Scenario 1	Scenario 2
Constant	8.817^{**} (2.07)	9.727 (1.79)
Time	$0.471\times10^{-2**}$ (2.20)	0.122×10^{-2} (0.51)
Sales	-0.170×10^{-4} (−0.61)	$-0.413\times10^{-4**}$ (−2.06)
Employ	$0.507\times10^{-1***}$ (5.15)	$0.338\times10^{-1***}$ (4.70)
Consumption	$0.573\times10^{-5***}$ (18.20)	$0.426\times10^{-5***}$ (19.11)
Emergency	$-0.354\times10^{-2**}$ (−6.53)	$-0.085\times10^{-2**}$ (−2.22)
Lamda	-24.147^{**} (−2.24)	-15.684^{*} (−1.88)

Values in parenthesis are z-statistics.
***, **, * Significant at 1%, 5%, and 10% level, respectively.

The author estimated outage cost using Type 1 Tobit model with the pooled data in order find what factors affects the outage cost. The model followed in the analysis is described as follows[40]:

$$y_i = \beta_0 + \beta_1.Time_i + \beta_2.Sales_i + \beta_3.Employ_i + \beta_4.Consumption_i + \beta_5.Emergency_i, \quad (2)$$

where

- $Time_i$ = power outage duration (minutes).
- $Sales_i$ = company annual sales (10 million KW).
- $Employ_i$ = full time employees.
- $Consumption_i$ = monthly average electricity consumption (kWh).
- $Emergency_i$ = emergency generator capacity (kW) of $company_i$

As shown in Table.6, the statistically significant variables estimated significantly affect the outage costs. According to Table.6, longer outage duration, a higher number of employees, higher monthly average electricity consumption, and smaller emergency generator capacity result in higher outage costs for scenario 1. In contrast, monthly sales have significance in scenario 2, while time does not. However, comparing two scenarios together, outage cost is highly affected by the emergency generator when the power outage happens in the announced case like scenario 1.

Table 7: Results of Type II Tobit model estimations for three different sectors [40].

	Agriculture, forestry, fishery, and mining		Manufacturing and construction		Commercial and public service	
Variables	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Constant	3.436^{*} (1.77)	0.443 (0.68)	5.575^{*} (1.76)	7.379^{*} (1.74)	0.309^{***} (3.20)	0.652^{**} (2.26)
Time	$0.209\times10^{-2**}$ (1.98)	0.043×10^{-2} (1.37)	$0.389\times10^{-2***}$ (2.59)	0.108×10^{-2} (0.61)	$0.039\times10^{-2***}$ (6.56)	0.981×10^{-4} (0.78)
Sales	0.017×10^{-2} (0.23)	-0.014×10^{-2} (−0.88)	0.395×10^{-4} (0.41)	0.734×10^{-5} (0.08)	0.935×10^{-4} (1.14)	0.144×10^{-4} (0.14)
Employ	0.674×10^{-1} (0.85)	$0.776\times10^{-1***}$ (4.48)	$0.434\times10^{-1***}$ (5.51)	$0.360\times10^{-1***}$ (4.95)	$0.242\times10^{-2***}$ (2.95)	$0.161\times10^{-2**}$ (2.02)
Consumption	-0.859×10^{-5} (−1.60)	-0.141×10^{-5} (−1.28)	$0.550\times10^{-5***}$ (12.64)	$0.517\times10^{-5***}$ (13.34)	$0.590\times10^{-6**}$ (2.44)	$0.422\times10^{-6*}$ (1.71)
Emergency	$0.313\times10^{-1***}$ (3.34)	-0.184×10^{-2}(−0.71)	$-0.424\times10^{-2***}$ (−5.52)	$-0.365\times10^{-2***}$ (−5.33)	$-0.063\times10^{-2**}$ (−2.11)	-0.040×10^{-2} (−1.37)
Lamda	-5.975^{*} (−1.73)	-1.328^{*} (−1.85)	-17.908^{**} (−2.07)	-13.560^{**} (−2.11)	-0.351^{**} (−2.31)	-0.719^{*} (−1.88)

Values in parenthesis are z-statistics.
***, **, * Significant at 1%, 5%, and 10% level, respectively.

Furthermore, data were separated into three main sectors, and each sector has different industries. Sector 1 contains agriculture, forestry, fishery, and mining industries. Sector 2 contains the construction and manufacturing industries. Sector 3 contains public service and commercial industries. The estimated results for both scenarios for each sector are shown in Table.7. From the results, for each sector, the statistically significant variables have different effects. For all sectors, time is statistically significant for scenario 1. For sectors 2 and 3 employ variable is statistically significant for both of the scenarios, while it is only statistically significant for scenario 2 in sector 1. For sectors 2 and 3 for both scenarios, consumption is statistically significant. All of the sectors for scenario 1 show significance with the emergency variable, while it is only significant for scenario 2 in sector 2. All sectors show a negative estimate for emergency except for scenario 1 in sector 1. This can be explained as when the power outages occur without pre-announcement, then the cost of operating the emergency generator is higher than the benefit.

Additionally, outage costs for scenario 1 are higher than the outage costs for scenario 2 in all of the sectors. This is due to the fact that if the information on the power outage is pre-announced to companies, then the outage costs decrease. Therefore, damages for the power outage can be minimized if the outage is being pre-announced to companies, which matches with [37] and [46]. Moreover, the average value of lost load (VoLL) was calculated for all surveyed companies, and the results of VoLL were compared to the results of average outage costs estimated earlier.

To summarize, Table.8 shows that estimated outage costs are 1.24 - 1.3 times higher than the simple VoLL calculations. This is because different kinds of damages were included in the estimated results. Moreover, from the tabulated results in Table.8 there is a huge difference in outage costs between companies with emergency generators and companies without emergency generators. Hence, outage costs for companies with emergency generators are 3.1 - 3.2 times higher than companies without emergency generators.

Table 8: summary of the results.

	VoLL (KRW) for an hour	Outage costs (KRW) for an hour	
		Scenario 1	Scenario 2
All companies	133.3 million	173.1 million	165.9 million
Companies with emergency generators		393.9 million	370.8 million
Companies without emergency generators		122.6 million	119.1 million

6.2 Evaluation of power outage costs for industrial sectors in Finland.

6.2.1 The model

Since the customer survey method is considered to be the most accurate in terms of providing customer-specific data [47],[48], it has been implemented in this paper. However, there are some concerns related to customer surveys when calculating the power outage costs, such as the results' subjectivity and strategic responses. Therefore, the author focuses on handling strategic responses matter only, analyzing subjectivity, and hence the reliability of customer surveys. In this paper, the author follows the z-score technique to interrupt the customer survey data. The z-score indicates how many standard deviations a data point is from the mean. The following equation represents the z-score as follow [51]:

$$z = \frac{(x - \mu)}{\sigma}, \tag{3}$$

where z is z-score, x is the value of data point, μ is the mean of the data set, and is the standard deviation of the data set. If there is a point outside the range of the typical data values in data sets, it is called an outlier. However, a point is called an extreme outlier when the absolute value of the z-score is greater than or equal to 3.0. The author has implemented the z-score to each data set and eliminated the outliers.

The customer survey approach from the paper Evaluation of power outage costs for industrial sectors in Finland was conducted on Finland's industry sector citeRef51. The study was conducted on 126 customers, and about 73% of the response rate has been reached. In this study, the customer survey the Direct Worth approach model has been implemented. One to one interviews, telephone calls, and email questionnaires. The power outage costs were collected via a study conducted at Aalto University, School of Electrical Engineering [49]. It is suggested that each industrial sector must be analyzed separately because the power consumption changes between customers depending on the size, the production amount, equipment used by the company, and the field that it operates in. furthermore, the author have divided the industrial sector into subcategories due to the mentioned reasons earlier. The subcategories are food, chemical, glass, paper, metal, timber, construction, and electrical. Two customer damage functions were defined in the article as each respondent was asked to estimate the power outage costs in Euros for different periods. The first customer damage function CICp is estimated by dividing the outage duration cost over the peak power. Where as the second customer damage function CICe is estimated by dividing the outage duration cost over the annual energy consumption as follow [51]:

$$CIC_p = \frac{Reported\ cost\ for\ t\ hours}{Peak\ power\ of\ the\ customer}, \tag{4}$$

$$CIC_e = \frac{Reported\ cost\ for\ t\ hours}{Annual\ energy\ consumption}, \tag{5}$$

The author used data set from reported industries for one hour. As the results were shown in a histogram were skewed to the right and not normally distributed, elimination and censoring were essential to carry out an accurate analysis to estimate the customer interruption costs for the industrial sectors. New data set was reached after eliminating the strategic responses using the z-score technique.

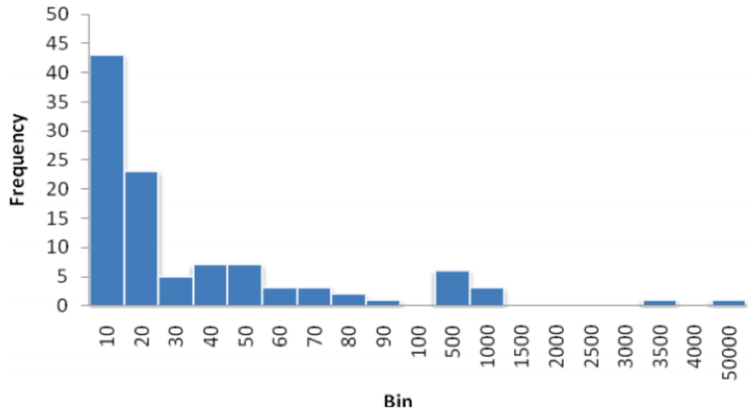

Figure 12: Industrial sector unexpected outage costs uncensored distribution for 1hour Euro/kW [51].

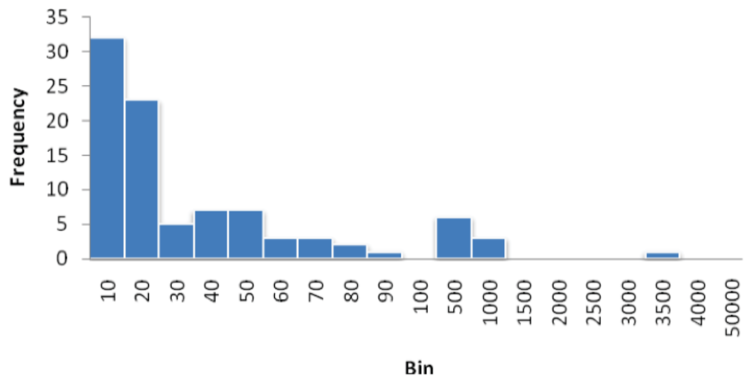

Figure 13: Industrial sector unexpected outage costs Censored distribution for 1hour Euro/kW [51].

6.2.2 Results and discussion

In the results, the author has only plotted and analyzed the customer damage functions (CDFs) of Reported cost in kW of peak power CICp. To estimate a function to calculate the CICs over a required time, a regression technique was implemented to determine the CICs' characteristics. However, because the linear regression does not result in precise results, a second-order polynomial regression was used. Moreover, The author has plotted only the results of metal and food industries where other sectors' results are summarized in a table and can be found in the article [51]. For the concision of this paper, plot and regression analysis will be shown.

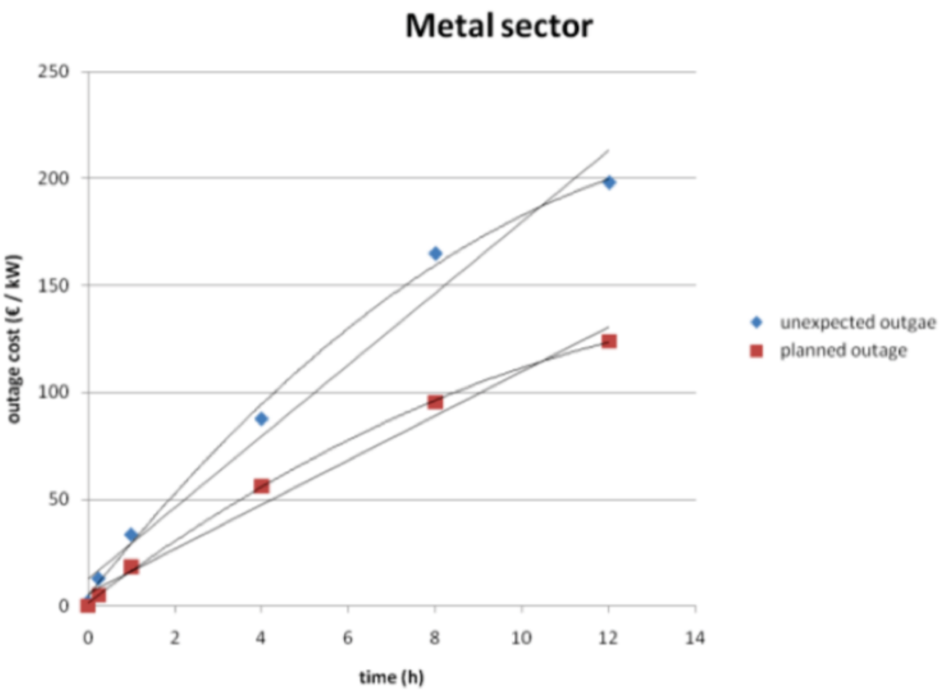

Figure 14: CICp for metal sector for both unexpected and planned outage scenarios in euro/kW [51].

Polynomial regression for unexpected outage [51].

$$CIC_p = -0.7756t^2 + 25.577t + 4.5357. \quad (6)$$

$$R^2 = 0.9969 \quad (7)$$

where

- CIC_p = peak power of the customer (euro/kW)
- t = time of an outage

Linear regression for unexpected outage [51].

$$CIC_p = 16.712t + 12.749. \tag{8}$$

$$R^2 = 0.9769 \tag{9}$$

Polynomial regression for planned outage [51].

$$CIC_p = -0.4221t^2 + 15.213t + 1.616. \tag{10}$$

$$R^2 = 0.9995 \tag{11}$$

Linear regression for planned outage [51].

$$CIC_p = 10.389t + 6.0854. \tag{12}$$

$$R^2 = 0.9841 \tag{13}$$

Comparing the R^2 values of both linear and polynomial regression shows that the second order polynomial shows higher accuracy than the linear regression in estimating the CICs. Results for the CICp's for unexpected outage and planned outage scenarios are shown in Tables 9, and 10, respectively.

Moreover, the results for CIC_e for unexpected outage and planned outage are shown in Tables 11, and 12, respectively [51].

As the author claimed, the customer survey method is considered the method in estimating customer interruption costs. When doing a customer survey, the Finnish economy's scale avoids extensive time demands and high monetary expenditure. Furthermore, the survey results were satisfactory to estimate the power outage economic costs in Finland for the industrial sector. Moreover, it is claimed that some respondents exaggerate their losses. Hence the author takes these factors into account, which affect the credibility of the direct worth approach. As a result, the author will focus on a new study based on indirect analytical methods to estimate the economic power outage worth.

Table 9: Peal power of unexpected outage scenario CICp's values for industrial sectors in euro/kW [50].

	unexpected outage		
	1h	4h	8h
metal	33.37	87.5	164.9
food	25.34	40.99	96.15
chemical	20.85	41.01	92.42
glass	48.94	197.16	221.74
paper	28.09	124.44	176.72
timber	15.40	67.87	131.75
construction	53.84	145.92	284.12
electrical	20.05	49.18	96.40

Table 10: Peak power of planned outage scenario CICp's values for industrial sectors in euro/kW [51].

	planned outage		
	1h	4h	8h
metal	18.33	56.05	95.34
food	9.64	21.70	71.81
chemical	16.77	20.28	39.69
glass	7.30	27.07	45.09
paper	24.40	102.04	160.97
timber	7.29	26.56	86.04
construction	40.89	124.35	260.86
electrical	9.07	22.76	49.57

6.3 Paper: A Novel Hybrid Approach to Estimate Customer Interruption Costs for Industry Sectors

6.3.1 Research method - data elimination

The author used the customer survey method, along with introducing new specific sector damage functions. The conducted survey method used follows the article [51]. In addition, n the forms of production loss, restart loss, losses of spoiled material, costs of third parties, damages, and other costs were requested for the intervals of 1hour, 4hours, and 8hours. Hence, this approach is called the relative worth approach as the customer reports the percentage of losses besides the direct

Table 11: Annual energy consumption of unexpected outage scenario CICe's values for industrial sectors in euro cents/kWh[51].

	unexpected outage		
	1h	4h	8h
metal	1.07	2.92	5.50
food	0.65	1.37	3.21
chemical	0.83	1.37	3.08
glass	1.63	6.57	7.39
paper	0.94	4.15	5.89
timber	0.51	2.26	4.39
construction	1.62	4.86	9.47
electrical	0.67	1.64	3.21

Table 12: Typical values of annual energy consumption for planned outage scenario CICe's values for industrial sectors in euro cents/kWh [51].

	planned outage		
	1h	4h	8h
metal	0.58	1.87	3.61
food	0.32	0.72	2.39
chemical	0.67	0.68	4.86
glass	0.24	0.90	1.50
paper	0.81	3.40	5.37
timber	0.24	0.89	2.87
construction	0.95	3.77	7.90
electrical	0.30	0.76	1.65

cost for the outage duration. The results are shown in Table 13.

Moreover data elimination followed the procedure as in [50] and histogram was modeled into log-normal histogram after z-score test and eliminating the outliers.

6.3.2 The model

CDF of CICva has been developed as the value-added and annual energy consumption data of industries access information. Annual energy consumption

Table 13: Average values of loss types in percentages for each industry sector [50].

Sectors	Production	Restart	Spoiled Materials	Damages	Third Party Costs	Other
Food	50	3	36	1	0	10
Metal	60	6	5	8	9	12
Paper	58	15	2	4	0	21
Chemical	43	25	6	0	0	26
Glass	50	9	4	5	0	32
Timber	67	12	2	3	12	4
Construction	74	12	1	1	5	7
Electrical	63	7	5	1	3	21

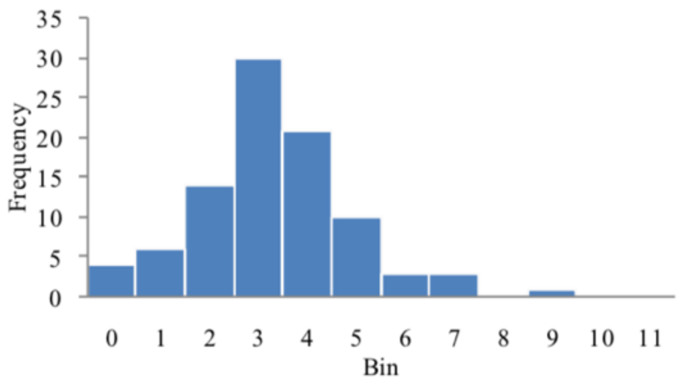

Figure 15: Censored lognormal distribution of the industry sector unexpected outage costs for 1 hour in euro/kW [50].

and value-added data of the industrial customers are objective and easy to reach information. CICva per hour can be estimated simply as follow [50]:

$$CIC_{va} = \frac{value\ added\ for\ 1\ year}{annual\ energy\ *\ 3000h} * t, \tag{14}$$

6.3.3 Unexpected outage weighing factor

Since power outages might occur at any time, unexpected outages add to the losses of companies. Therefore, to link between the realistic value CIC and the actual value-added weighing factor Ku has been developed, and it can be found as follow [50]:

$$Ku = \frac{100}{percentage\ of\ production\ losses}, \tag{15}$$

where the percentage of total losses is a combination of the production losses, restart losses, losses of spoiled material, damages, third party costs, and other costs.

The governing new subsector customer damage functions SSCDFs for unexpected outage is defined as follow [50]:

$$CIC_u = K_u * CIC_{va} , \tag{16}$$

6.3.4 Planned outage weighing factor

In planned outages, the characteristics that affect the CIC are different from those in the unexpected outage. When the planned outage happens, companies can minimize the losses. Therefore, to link between CICae and the value-added information, a weighing factor Kp was developed[50]. In the case of planned outages, most industries suffer from production losses and restart losses, and hence these two measures were taken into consideration. Hence, the governing equations are as follow [50]:

$$K_p = \frac{percentage\ of\ production\ losses + percentage\ of\ restart\ losses}{percentage\ of\ production\ losses} , \tag{17}$$

$$CIC_p = K_p * CIC_{va} , \tag{18}$$

6.3.5 Results

New SSCDF CICpp, CICae, CICva, CICu, CICp, and weighing factors Kp and Ku were calculated to meet industries different characteristics to estimate the power outage interruption costs. Censored average values of Ku and Kp for each sector are shown in Tables 14, and 15, respectively.

Figs.16, and 17 show the ration of CICae vs. CICu and the ratio CICae vs. CICp.

From the results, the ratio approaches unity when the difference between the direct method and the relative worth approach decrease as the outage increases.

Table 14: Typical values of Ku weighing factors for different industry sectors [50].

Sectors	1 h	4 h	8 h	Average
Food	1.96	2.01	2	1.99
Metal	1.87	1.61	1.56	1.68
Paper	1.86	1.72	1.58	1.72
Chemical	3.48	2.17	1.88	2.51
Glass	2.37	1.91	1.79	2.03
Timber	1.71	1.52	1.32	1.52
Construction	1.43	1.31	1.31	1.35
Electrical	1.71	1.61	1.47	1.6

Table 15: Typical values of Kp weighing factors for different industry sectors [50].

Sectors	1 h	4 h	8 h	Average
Food	1.1	1.05	1.05	1.06
Metal	1.23	1.06	1.05	1.12
Paper	1.3	1.26	1.23	1.26
Chemical	1.96	1.44	1.53	1.64
Glass	1.45	1.11	1.07	1.21
Timber	1.3	1.18	1.08	1.19
Construction	1.16	1.15	1.15	1.16
Electrical	1.21	1.08	1.05	1.11

Also, the method is suitable to estimate interruption costs when the outage duration is longer than 15 minutes. In order to determine the relationship of these functions, the correlation between SSCDF CICae and econometric models of SSCDF CICu and CICp was examined. The author plotted the food sector results, as shown in Figs.18, and 19, where other sectors were tabulated, as shown in Table 16.

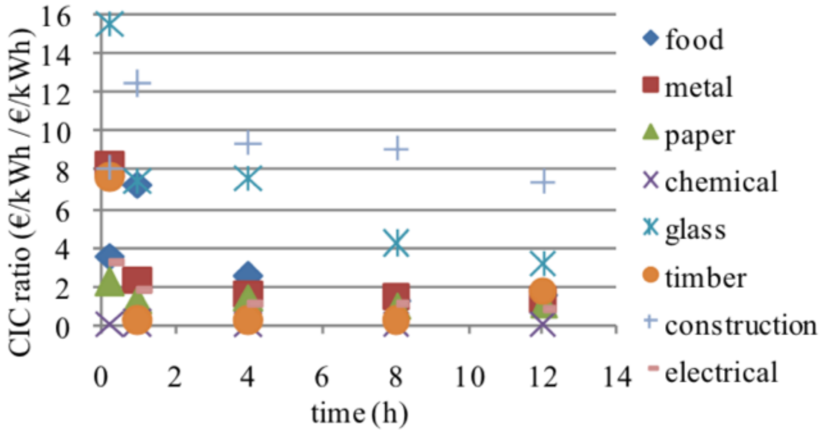

Figure 16: CICae/CICu ratios of industry sectors for the unexpected outage scenario [50].

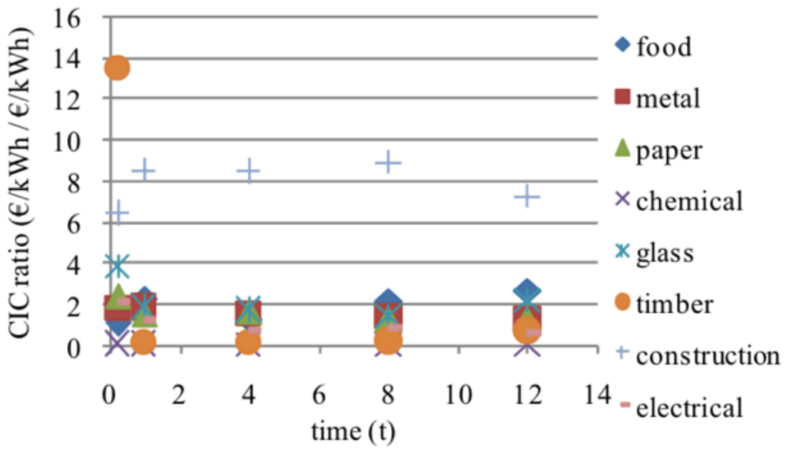

Figure 17: CICae/CICp ratios of industry sectors for the planned outage scenario [50].

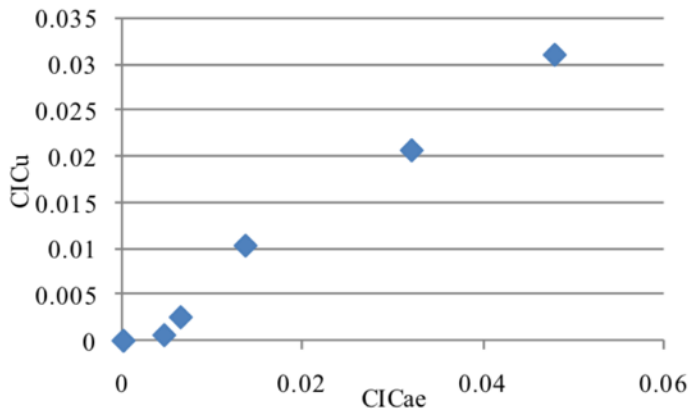

Figure 18: The correlation between CICae and CICu for the food sector for the unexpected outage scenario [50].

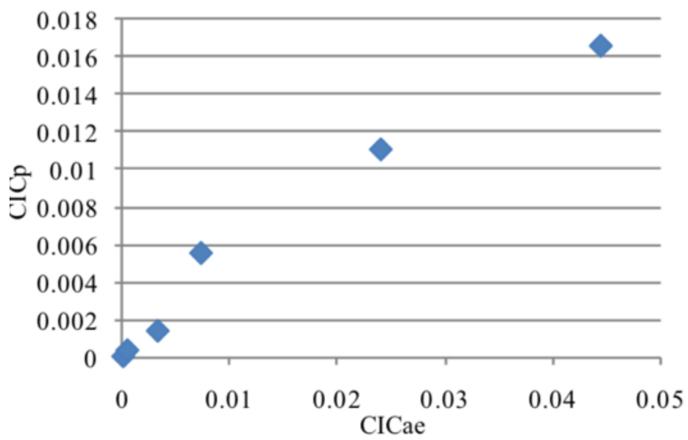

Figure 19: The correlation between CICae and CICp for the food sector for the planned outage scenario [50].

Table 16: The correlation coefficients for the industry sectors for both unexpected and planned outage scenarios respectively [50].

Sectors	CICae-CICu	CICae-CICp
Food	0.99	0.98
Metal	0.99	0.99
Paper	0.99	0.99
Chemical	0.99	0.95
Glass	0.92	0.97
Timber	0.81	0.73
Construction	0.99	0.99
Electrical	0.98	0.99

Econometric models are considered fast, objective and cheap in terms of estimating CICs. To compare the results of econometric models and direct costing approach, Table 17 shows the CICpp for the examined sectors.

Table 17: Typical values of CICpp's for industry sectors in €/kW of peak power for unexpected outage scenario [50].

Sectors	1 s	15 min	1 h	4 h	8 h	12 h
Food	0	5.81	25.34	41	96.15	143.64
Metal	1.91	12.68	33.37	87.5	164.9	198.13
Paper	1.26	11.7	28.09	124.44	176.72	272.97
Chemical	0	3.62	20.85	41.01	92.42	118.18
Glass	3.91	27.65	48.94	197.16	221.74	251.47
Timber	1.49	6.67	15.4	67.87	131.75	165.17
Construction	0.08	15.85	53.84	145.92	284.12	346.48
Electrical	5.67	8.67	20.05	49.18	96.4	109.33

7 Discussion

Table 18: Comparison between literature findings.

Paper	Aim	Method	Approach	Sample	Results	Limitations or improvements
1[I]	Estimation of outage costs including direct and indirect costs of South Korea customers for the industrial sector	Customer survey on company's level followed Tobit II model was implemented to interrupt the result.	Direct Worth	430	Estimated variables that has an effect on the outage costs, emergency generator was found to have biggest effect on the outage costs.	Scale of collected data. Hence, results cannot be generalized for each industry. Also Tobit II model assumptions limitations.
2[II]	Estimation of outage costs of Finland customers for the industrial sectors.	Customer survey followed by a regression analysis	Direct Worth	126	Estimated variables which has an effect on the outage costs and presented the outage cost for sampled industries.	Scale of collected data. Regression analysis limitations.
3[III]	Introducing new CDFs to estimate outage costs for industrial customers sector.	Customer survey followed by indirect analytical method.	Relative Worth	126	Presented new CDF to estimate outage costs for the industrial sector	To reach more accurate results more subsector specific CDF might be needed with new weighing factors.

Table (18) summarizes the comparison between [40][50][51]in terms of the aim the author wanted to reach, approach used, data size, results and limitation in the method or improvements which could be implemented. To begin with, the author of the paper [40] aims to estimate the outage costs of South Korea customers for the industrial sector. Since Customer survey was a common method between the three papers common issues existed. The issue of the survey implies of the reliability of the answers. Some customers tend to exaggerate with theirs losses where some might be in a rush resulting in unreliable answers. Moreover, such responses would high affect the outcome of the study that is to estimate CICs. It is true that data elimination processes work on filtering the data to the maximum level where it can fit a normal distribution. However, some issues arise when starting to implement the suggested models such as the regression analysis with the censored data. [1] [2] [3]

In the cases studied it is been found that linear regression is commonly used as the main statistical tool by taking a sample from the population and make inferential statistics about it. Despite the wide use of such a tool it doesn't come without limitations. The limitations of linear regression mainly lie in the model assumptions and the level at which these assumptions can hold. As the name suggests, linear regression fundamentally assumes that the true underlying relation between the dependent and independent variable(s) is linear, which, even though, can be justified by theory might not hold for the data generating process. Secondly, in the finite sample context, the model assumes strict independent relation between the regressors (the independent variables) and the error term (unobservable) which more often than not doesn't hold due to either, omitted variable, serial correlation or heteroskedasticity. If any of the previous assumptions doesn't hold the estimated coefficient are expected to be biased. Moreover, in order to be make, test statistics the model has to assume the error term to be normally distributed otherwise the statics used will lack known distributed to test against. As theses type of assumptions seems to be bold. Large sample theory has been developed to relax some of them.

On the other hand, in the context of the large sample theory (Asymptotic), we could have more relaxed assumptions. By imposing restrictions on the underlying data generating process. For instance, the strict exogeneity assumption could be replaced by just contemporaneous independence (predetermined regressors) and the normality assumption could be assumed based on the type of the DGP (martingale difference sequence). Even though the asymptotic context could be robust toward conditional heteroskedasticity still it is vulnerable toward serial correlation, perfect-collinearity and endogeneity.

The failure in any of these assumptions could lead to biased estimated and invalid inferential statistics. All models suffer from certain limitations, but researchers should be aware of such limitations and their imbedded implications on their results. By projecting on the literature reviewed. When such implications arises advanced estimators instead of OLS could be utilized to account for them, for instance, the use of the robust estimators in case of having outliers that could affect the OLS estimator since the OLS is crucially sensitive to outliers or in case of having endogeneity bias, two-stages least squares (2SLS) or of Generalized Method of Moments (GMM) could be used instead. T hese estimators usually are not being utilized by non-specialized researches due to the complications in the mathematics involved

[1]Estimation of power outage costs in the industrial sector of South Korea [40]
[2]Evaluation of power outage costs for industrial sectors in Finland[51]
[3]A Novel Hybrid Approach to Estimate Customer Interruption Costs for Industry Sectors[50]

8 Conclusion

Electricity is a vital factor in our daily life. Almost all activities depend heavily on electricity, starting with people's personal uses and up to big scale industries such as food, metal, manufacturing, etc. Therefore, the continuity of electric supply is crucial for the continuous development of industries and rolling of life routines. Likewise, natural disasters like storms or hurricanes can paralyze the chain of production as such extreme weather events would cause a power interruption as mentioned in detail in the literature review part. Hence, with the frequent occurrence of these extreme weather events and the problems associated with power interruptions, it became essential to identify the reasons behind these blackouts and assess a method in order to estimate the customer interruption costs. Between the three approaches to estimate CICs, customer survey is the most common method used to estimate CICs. Furthermore, when addressing the cause of power interruptions it gives a better understanding of how to approach a specific solution. Frequent storms in Finland that started in 2010 and until 2013 resulted in major losses for electricity customers. However, it pushed the authorities to improve the electrical network in Finland as 3000 km of new transmission lines was constructed and 30 new substations covering rural areas. Plus, replacing the old infrastructure with newer one. On the other hand, in South Korea the rapid electrification is the main reason for power interruptions as mentioned earlier. Consequently, after going through the literature an integrative review was made to list all possible solutions researches has reach to and seek opportunities for further developments. To conclude, the estimation of CICs for industrial sector in South Korea was found to be 1.3 times higher than the simple VoLL calculations. The approach implemented took in account all possible losses that has an effect on the CICs just like the relative worth applied in Finland. Also, all of the studied cases had suffered from the small size of data collected and the reliability of the responses. In Comparison of the cases studied, approaches to estimate CICs in paper [50] presented unique set of solutions that made it stand out. Besides estimating variables which have an effect on the CICs like [40] new SSCDF were introduced to meet each sector specific needs. The new functions CICpp, CICae, CICva, CICu, CICp and weighing factors Ku and Kp made it easier to reach reliable figures when estimating CICs.

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